ACID BASE DISORDERS

The Clinical Use of the Astrup Method of Determining pH, pCO_2 and Base Excess

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■ *The Astrup method for determination of arterial pH, pCO_2, and "base excess" provides a simple and accurate means for quantitation of acid-base disorders. The "base excess" value, a measure of metabolic acidosis or alkalosis, gives the clinician a valuable tool with which to estimate electrolyte replacement. The pCO_2 is a measure of respiratory acidosis or alkalosis. The pH is used as a measure of the adequacy of compensation. Several representative cases illustrate the use and interpretation of the test.*

THE INTRODUCTION of the flame photometer stimulated interest and reliance upon electrolyte determinations in acid-base disorders. It has become obvious that determinations of serum electrolytes alone do not give complete information and may be misleading. Frequently one cannot tell the difference between metabolic acidosis and respiratory alkalosis in a condition such as salicylate intoxication. The determination of whole blood pH, pCO_2 and base excess or deficit provides information not available from electrolyte determinations alone.

It is possible to quantitate, by the use of Astrup's nomogram,[1,7] the degree of metabolic and respiratory acidosis or alkalosis. The degree of base excess or deficit has important implications regarding the quantity and type of necessary electrolyte replacement. The complete acid-base profile can be obtained by the Astrup method in less time than it takes to perform the CO_2 combining power determination.

Since considerable confusion in terminology often arises in discussion of acid-base disorders, the terms should be defined.[3]

Acidemia: Lowering of blood pH below 7.35;

Alkalemia: Elevation of blood pH above 7.45;

Acidosis: A change in respiratory or metabolic status which, if not compensated, would cause an acidemia;

Alkalosis: A change in respiratory or metabolic status which, if not compensated, would cause an alkalemia.

From clinical laboratory, Providence Hospital, Portland, Oregon. Submitted March 16, 1964.

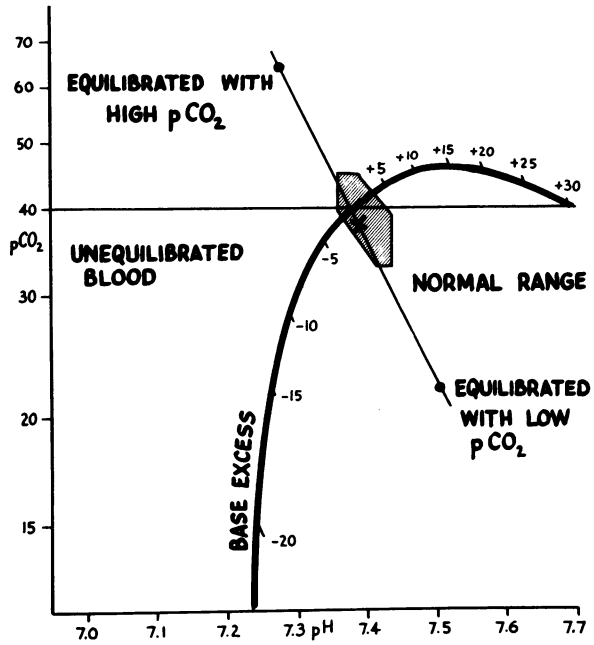

Chart 1.—Astrup nomogram. Points of equilibration of blood with known CO_2–O_2 gas mixtures define the line. The pH of the unequilibrated blood sample was 7.39. The pCO_2 read from the nomogram was 38 mm of mercury. The shaded polygon is the normal range.

Determination Method

For the Astrup method, whole blood obtained from an artery or arterialized capillary is used. It must be obtained anaerobically, and is kept at 4°C until the determination is carried out. The measurements are made on a temperature-controlled pH meter, described by Astrup,* which requires only 0.025 ml of blood and may be performed up to three hours after the blood is obtained.[6] Three pH measurements using whole blood are necessary. One reading is that of the unaltered blood as received from the patient. The other two readings are of blood equilibrated in a tonometer at 37°C with different CO_2–O_2 mixtures. The chosen CO_2 tensions are such that one is approximately 20 mm of mercury and the other approximately 60 mm of mercury. The former is lower and the latter higher than the normal blood tension. The two points are plotted on a pH vs log pCO_2 graph (Chart 1) and a straight line is drawn through the points.

The pH of the unequilibrated blood can be located on the line to give the patient's pCO_2. The slope of the line is related to the buffering capacity of the blood. A 45° angle is the line describing the Henderson-Hasselbalch equation applied to the bicarbonate-carbonic acid system. A steeper line indicates greater buffering.

The "base excess" is determined by reading the value at the intersection of the patient's pH vs log pCO_2 line and the "base excess" curve of the nomogram. The "base excess" was derived by Astrup by drawing the curve obtained by adding known amounts of acid or base to a normal blood sample.

Principles of Interpretation

Examination of the Astrup nomogram reveals that in almost every case there is both a respiratory and metabolic component. Each must be analyzed separately. A new definition of terms is now possible.

Respiratory acidosis: pCO_2 above 45 mm of mercury;

Respiratory alkalosis: pCO_2 below 35 mm of mercury;

Metabolic acidosis: "Base excess" below −3 mEq per liter;

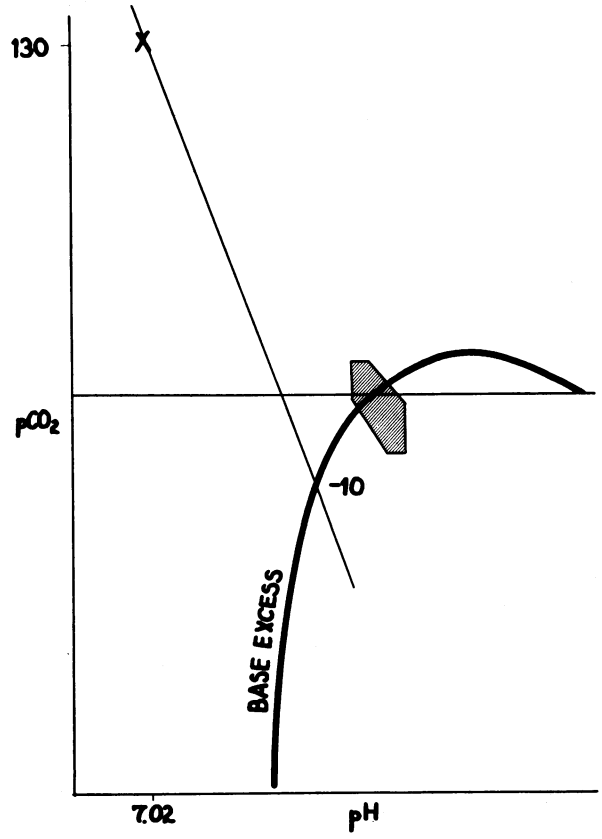

Chart 2.—Acute respiratory obstruction. A 7-year-old girl was operated on for a lacerated bronchus. During operation it was noted that her respirations were rapid but her color was poor. The very high pCO_2 of 130 mm of mercury and severe acidemia, pH 7.02, directed attention to the anesthesia airway, which contained too much dead space. Therapy consisted of shortening the airway. Serum electrolyte values during the acute episode were: CO_2 16 mEq per liter, Na 132 mEq per liter, K 3.8 mEq per liter, Cl 103 mEq per liter. The metabolic acidosis, "base excess" −10, may be explained by the trauma, preoperative starvation or dehydration.

*Astrup Ultra-micro apparatus, Radiometer model AME-1, The London Company, 3355 Edgecliff Terrace, Cleveland 11, Ohio.

Metabolic alkalosis: "Base excess" above +3 mEq per liter.

It must be borne in mind that knowledge of the patient's history is necessary for intelligent interpretation of a record. It is impossible to determine from the record alone which alterations are primary and which are a compensatory response. In a recent paper Schwartz and Relman[5] pointed out the difficulty in terminology which arises when one compares an alteration due to a primary condition with an alteration which is compensatory. The above definitions may also be modified when one acid-base derangement is superimposed upon another. The items which are important are:

(a) pCO_2, for presence and amount of the respiratory component;
(b) "Base excess," for presence and amount of of the metabolic component;
(c) pH, for adequacy of compensation.

Analysis of Cases

The usefulness of this test will become evident if representative cases of various disease states are analyzed.

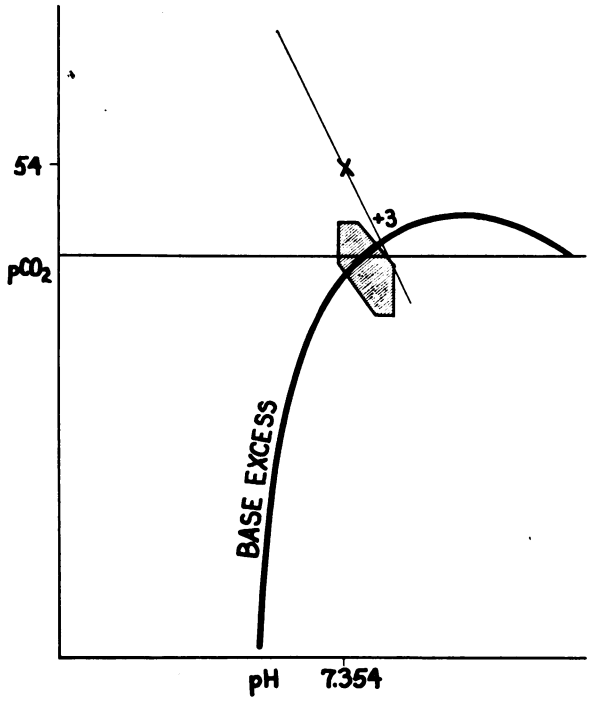

Chart 3.—Chronic respiratory acidosis. A 61-year-old man had silicosis and far advanced tuberculosis with episodes of dyspnea. At the time of the test, respirations were 20 per minute. The respiratory effort was great. The level of pCO_2 is typical of far advanced chronic pulmonary disease. One usually finds a slightly higher "base excess" in these cases.

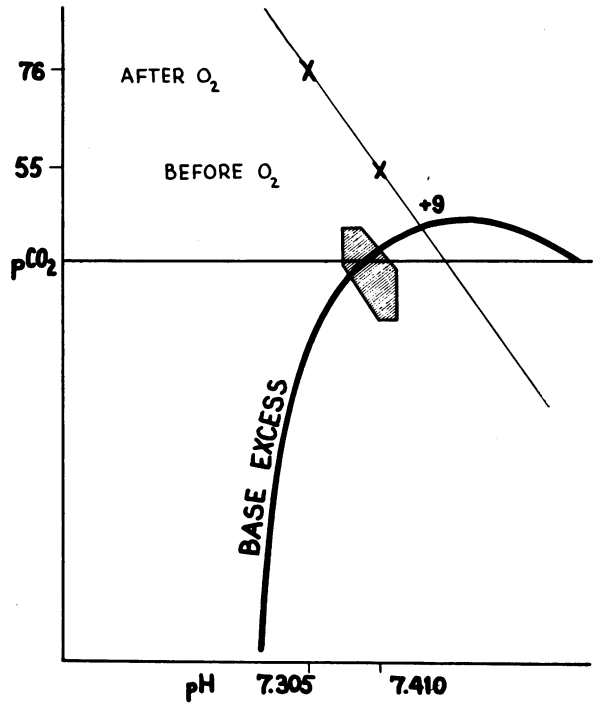

Chart 4.—CO_2 narcosis test. A patient with pneumoconiosis was tested for CO_2 narcosis. After breathing oxygen for 15 minutes there was an increase in the pCO_2 of 21 mm of mercury, which indicated that it would be dangerous for this patient to receive oxygen.

Respiratory Disease

Acute respiratory obstruction may cause very high pCO_2 values without appreciable metabolic compensation. The resulting acidemia may be extreme. Chart 2 illustrates such a case. After a period of a day some metabolic compensation can usually be seen.

In chronic respiratory disease, without an acute additional insult such as infection, the picture is different. All our records were made while the patient was awake and often strenuously hyperventilating. Had the record been made with the patient asleep, the pCO_2 might have been higher. In cases in which the degree of pulmonary disease was severe, the waking pCO_2 level was moderately elevated usually to between 50 and 60 mm of mercury. Chart 3 illustrates such a case. Sometimes the pCO_2 was normal or near normal, but the base excess was elevated to a moderate level of +4 to +7. The resulting blood pH was in the normal or slightly alkalemic range.[4] Apparently, there was some metabolic over-compensation.

CO_2 Narcosis Test

Patients with pulmonary disease are often considered for oxygen therapy to relieve symptoms. Many of these patients are suffering from CO_2 narcosis, and their respiratory center is no longer

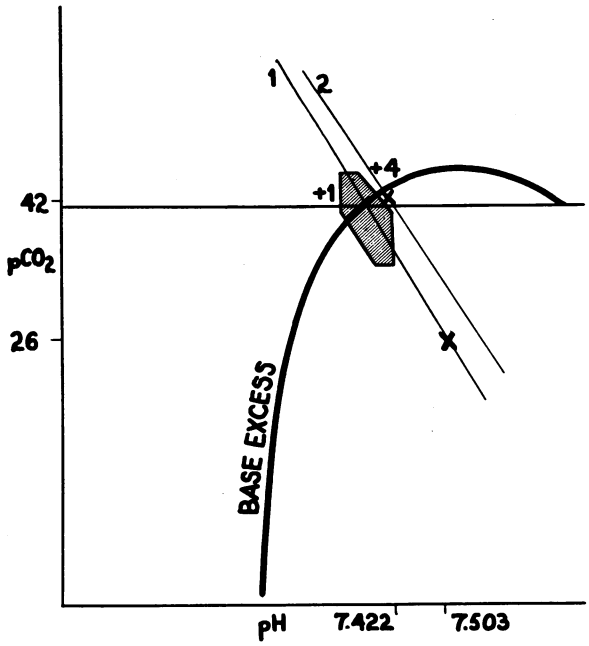

Chart 5.—Hyperventilation with respiratory alkalosis. A 35-year-old man was hyperpneic following evacuation of an epidural hematoma. The respiratory rate was 38 per minute. The anesthetist added 150 ml of dead space to the airway. A second determination was performed the following day when the respiratory rate was 24 per minute. Day 1: pCO_2, 26 mm of mercury; base excess, +1 mEq per liter; pH, 7.503. Day 2: pCO_2, 42 mm of mercury; base excess, +4 mEq per liter; pH, 7.422.

sensitive to the pCO_2. The sole respiratory stimulus is therefore hypoxia. Relieving hypoxia depresses respiration and may result in apnea. As a test for CO_2 narcosis, the following procedure was devised. An ordinary Astrup determination is performed. The patient, under close observation by the physician, is given oxygen to breathe by mask or nasal catheter. At the end of 15 minutes a second determination is performed. Since no shift in base excess should occur, a shortcut can be taken. The test can be performed by making a baseline measurement in the usual way and then measuring only the pH of the blood after breathing oxygen. The second point is located on the original pH vs pCO_2 graph. A rise in pCO_2 indicates that the respiratory center is responsive to hypoxia, but not pCO_2. Administration of oxygen would therefore be dangerous. Chart 4 illustrates the use of the test.

Hyperventilation with Respiratory Alkalosis

On occasion Astrup determinations have been performed on a patient because of dyspnea. Usually, the clinician suspects CO_2 retention, and is considering use of a respirator or performing tracheotomy. The case illustrated in Chart 5 is one such problem. The hyperventilation, of short duration, was due to central nervous system trauma. The pCO_2 was lowered and the blood pH elevated. The normal "base excess" indicates a lack of metabolic compensation. These acutely alkalemic patients frequently demonstrate a very low potassium level.

Metabolic Acidosis

The metabolic compensation for a primary pulmonary disorder develops slowly, while respiratory compensation of metabolic disorders occurs rapidly. Patients with metabolic acidosis have a "base excess" less than zero (minus "base excess"). In most cases there is a compensatory respiratory alkalosis (pCO_2 less than 40). Chart 6 illustrates a case of severe metabolic acidosis with extreme acidemia. Note the elevated serum potassium level, frequently seen in severe acidemia.

Metabolic Alkalosis

The diagnostic feature seen in metabolic alkalosis is an elevated "base excess." Potassium depletion and metabolic alkalosis frequently occur together. As a general rule, when the "base excess" is above +10, one should consider potassium replacement.

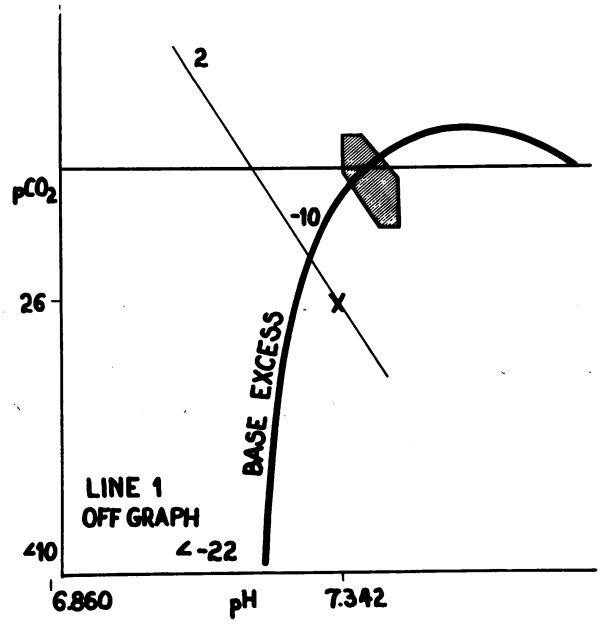

Chart 6.—Metabolic acidosis. An 8-week-old infant weighing 4.3 kg had diarrhea for one week. She entered the hospital dehydrated and hyperpneic. The initial values, line 1, are off the graph. Electrolyte replacement therapy consisted of 28 mEq of $NaHCO_3$ in the first 24 hours. In calculating the quantity of $NaHCO_3$ to be given, a normal extracellular volume of 300 ml per kg was assumed. Line 2 represents the values found 24 hours after the institution of therapy. CO_2 was determined by a titrametric method. Test values were:

		(mEq)			(mEq per Liter)			
Day	*Time*	*pCO_2*	*BE**	*pH*	*CO_2*	*Na*	*K*	*Cl*
1	4 p.m.	<10	<−22	6.860	−5	136	8	124
	9 p.m.	..	..	....	13	144	4.8	...
2	8 a.m.	..	..	....	15	135	4.5	112
	4 p.m.	26	−10	7.342	..	...	..	...

*BE=Base excess.

The serum potassium level is not a reliable guide because it is related to the blood pH. Chart 7 illustrates a case of severe metabolic alkalosis. Frequently, there is a history of loss of fluid from the upper gastrointestinal tract or of steroid therapy.

Complex Problems

There are cases in which more than one primary process is at work. One such example is seen in aspirin poisoning (Chart 8). Early in the toxic state there is respiratory alkalosis followed by primary metabolic acidosis. Therapy depends upon the phase of the condition.

Discussion

The Astrup method for investigating problems of electrolyte imbalance clarifies difficult situations by separating and quantitating the metabolic and respiratory components. Each must be taken into consideration in order to institute appropriate therapy.

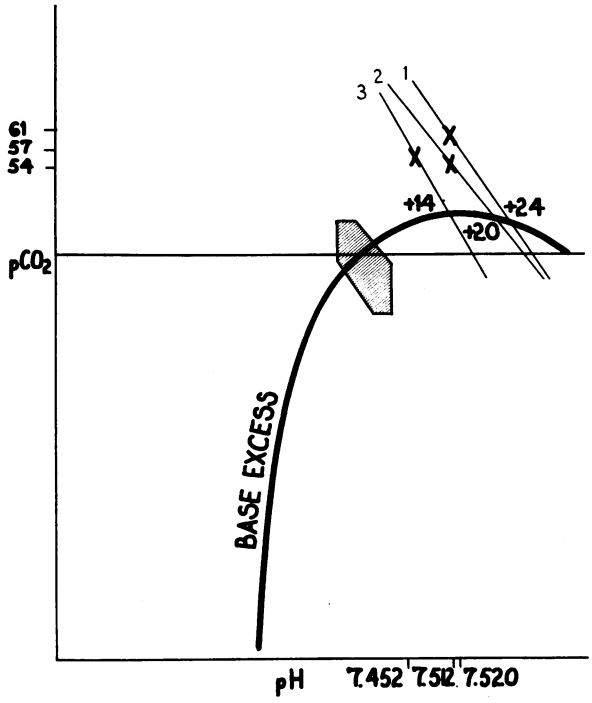

Chart 7.—Metabolic alkalosis. A 5-month-old boy with a neurological disease associated with arthrogryposis had pneumonia and persistent severe vomiting. He was dehydrated and weighed 4 kg. The Astrup test showed a decidedly elevated "base excess" and a partially compensating retention of CO_2. During the first 24 hours he received 650 ml of one-fourth normal saline plus 13 mEq KCl were given. Additional potassium was given following the final record. Test values were:

Day	(mEq) pCO_2	BE*	pH	(mEq per Liter) CO_2	Na	K	Cl
1	61	+24	7.520	..	...	..	73
2	54	+20	7.512	41	131	3.6	78
3	57	+14	7.452	..	128	4.4	82

*BE=Base excess.

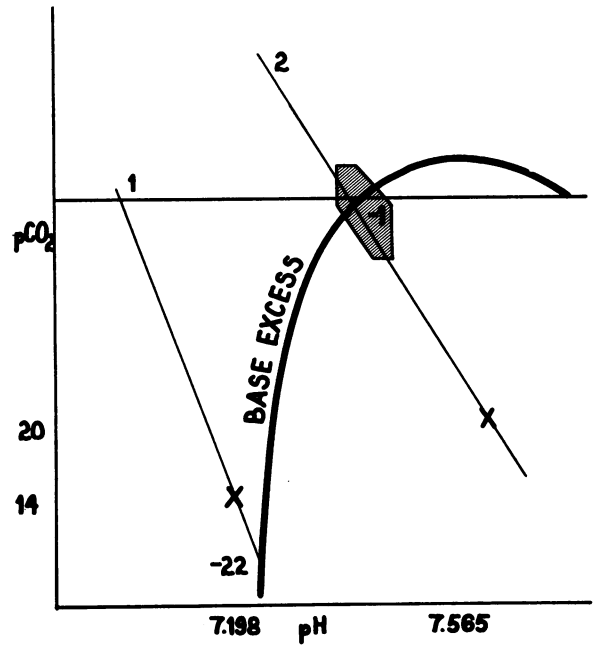

Chart 8.—Salicylate intoxication. A 5-year-old child was seen a few hours following ingestion of 13 aspirin tablets. Therapy consisted of 50 mEq sodium lactate. The acidifying effects of the aspirin were completely reversed by lactate therapy, although the central nervous stimulation continued. Laboratory test results were:

Day	(mEq) pCO_2	BE*	pH	(mEq) CO_2	Urine pH	(mg per 100 ml) Serum Salicylate
1	14	−22	7.198	10	5	58
2	20	−1	7.565	19.5	5.5	33

*BE=Base excess.

There are several possible sources of error which must be kept in mind in interpreting the test results. Respiratory changes occur rapidly. Either unusual hyperpnia or breath-holding by the patient will be reflected in the test results. An example of this (Chart 9) was provided by a subject who held his breath for 30 seconds. The resultant pCO_2 was 53 mm of mercury, and the pH was 7.360. The subject then hyperventilated for 30 seconds, driving the pCO_2 to 28 mm of mercury and the blood pH to 7.550. A similar situation is seen in some of the patients with chronic lung disease who have a normal pCO_2 at the time of examination. The only abnormality is an elevated "base excess," which indicates metabolic compensation for prolonged respiratory acidosis. A probable explanation of the discrepancy is hyperpnia on the part of the patient when the blood is drawn. A second source of error can be changes in the specimen after the blood is drawn. Refrigeration and the exclusion of air can minimize these changes.[6]

Electrolyte therapy should be based upon the "base excess" value. This indicates the quantity of

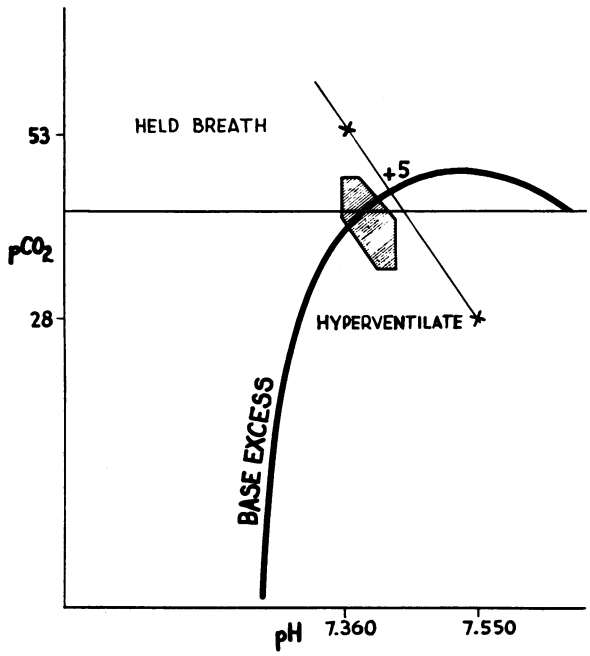

Chart 9.—Respiratory effects. A normal subject held his breath for 30 seconds. His pH was then 7.360 and his pCO_2 was 53 mm of mercury. After hyperventilating for 30 seconds his pH rose to 7.550 and his pCO_2 fell to 28 mm of mercury. The "base excess" of +5 mEq per liter reflects the normal postprandial metabolic alkalosis. A determination performed 3 hours later, just before lunch, showed a "base excess" of −2 mEq per liter.

fixed acid or base in the blood compared to the normal. It gives a good guide to the degree and direction of the metabolic acidosis or alkalosis. Astrup[6] recommended that electrolyte deficits in the extra cellular space be calculated using the formula:

Total deficit mEq =
"Base excess" × 0.3 × body wt Kg

The figure 0.3 approximates the extracellular fluid volume expressed in liters per kilogram of body weight for the normal adult male. This amount of the proper electrolytes should be given in an infusion, and repeat determinations should be performed before additional therapy is given.

The advantages of the Astrup system are its technical simplicity and speed and the ability to graphically clarify complex chemical relationships. The results of this test can serve only as a guide to therapy. In using the system one must always consider the patient's history, and the usual physiological patterns of compensation of acid-base disorders.

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